THE EVALUATION OF A MOTION BASE DRIVING SIMULATOR IN A CAVE AT TACOM

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ABSTRACT

The purpose of this presentation is to describe the highlights of a research program designed to investigate the feasibility of creating a motion base driving simulator in a Cave Automatic Virtual Environment (CAVE). The goal of the project was to create the most effective simulator possible using a compact, portable motion system. In addition to reviews of state-of-the-art simulation technology, two human factors studies were conducted to determine the impacts of design trade-offs on off-road driving performance in the simulator. In the first study, field of view (FOV), display system, and motion cueing algorithm were evaluated. In the second study, the optimum configuration from the first study was compared to off-road driving performance in TACOM's Ride Motion Simulator (RMS). In addition to performance evaluation, several simulator sickness mitigation techniques were also tested. The important findings from each of these evaluations will be discussed.

1. INTRODUCTION

Realtime Technologies, Inc. (RTI) was funded by TACOM through a Small Business Innovative Research (SBIR) contract to research the technical feasibility of adding realistic motion to an immersive virtual reality device known as the CAVE. The goal of the research program was to develop the most effective driving simulator using CAVE and compact motion base technologies. The primary application of the resulting simulator is human-in-the-loop, virtual vehicle design research. These same technologies also have other potential applications in the development of compact, portable driver training simulators. These types of simulators could be used to support the rapid development and delivery of timely driver training programs in support the operational and safety training needs of deployed forces.

Military vehicles often have requirements to perform well in both on- and off-road driving environments. Therefore, the virtual vehicle design system being developed here focused on optimizing simulation cue presentation for difficult off-road driving conditions. These conditions include steep grades, side slopes, embedded roadway obstacles such as rocks and down trees, etc. Typically, off-road driving is conducted at lower speeds than on-road driving and the driving task itself changes as a result of the different challenges that off-road conditions present. The off-road driving task involves being able to accurately perceive the driving terrain including the identification and assessment of roadways hazards. Off-road drivers must continually evaluate the driving terrain, their intended direction of travel, and the capabilities of their vehicle to determine the best possible driving path. These tasks often require a more detailed visual perception of the physical roadway and obstacle geometry than what is required to drive on-road. Therefore, both the visual presentation of the driving terrain and the motion cue and control loading responses are important factors in off-road simulator design.

Simulator sickness has traditionally been a challenge with driving simulation. Simulator sickness or the report of ill feelings associated with the use of simulation devices has been around for a long time. It can result in an array of symptoms including eye strain, headache, postural instability, sweating, disorientation, vertigo, pallor, nausea, and vomiting. These symptoms are brought about by a mismatch between visual and vestibular perceptual cues which result in perceived motion or vection (Kennedy, Hettinger, and Lillenthal, 1988).

Simulator sickness symptoms can affect an operator's performance in a variety of negative ways causing inappropriate behaviors, loss of motivation, avoidance of tasks that are found disturbing, distraction from normal attention allocation processes, and a pre-occupation with the fact that something is not quite right. Given the potential consequences of simulator sickness, it is important to understand the level of sickness subjects might be experiencing and how it affects their performance. Several new methods of mitigating simulator sickness and nausea have been proposed and will be studied in the following experiments. These methods include the independent visual background (IVB) and a medical device called the ReliefBand.

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The IVB consists of a grid superimposed over the out the window visual display. Regardless of how the displayed image moves during the simulation, the grid stays fixed to the earth reference coordinate system. The hypothesis is that the grid provides stable earth-stationary references that help the brain maintain a solid frame of reference for orientation. This helps alleviate any confusion the brain might have over what is or is not moving with respect to self orientation.

The ReliefBand is a medical device that is used by patients suffering nausea due to motion sickness, pregnancy, and chemotherapy. The device works by providing electrical stimulation to a nerve in the wrist that is associated with the control of normal contractions in the stomach. Nausea occurs when the stomach departs from its normal contractual rhythm. The stimulation helps keep the stomach in its normal rhythm of contraction.

1.1 Phase I Development

Phase I of the SBIR project resulted in the achievement of a number of technical development goals including the integration of RTI's driving simulator with a compact 6 degree of freedom (DOF) motion base in a CAVE. The CAVE used for this experimentation included three eight foot walls of a standard CAVE cube display. This configuration provided 270 degrees forward horizontal FOV and 90 degrees vertical FOV.

The 6 DOF motion mini-motion base may be seen in figure 1 below. The physical operating capabilities of the motion base include orientations of +/-15 deg. of pitch roll, and yaw and translations of +/-1 in. of sway, surge, and heave. RTI's SimCreator software was used to develop motion cueing algorithms that could be easily configured to run with different motion cue parameter sets including a 6 DOF and 3 DOF (roll, pitch, and heave) response profiles. In addition, individual tuning parameters such as motion gain, response limit, and response frequency could also be adjusted quite easily for each degree of freedom.

To complete the proof of concept development process, a pilot study was conducted with the Phase I simulator configuration. The study was conducted in such a way that test drivers could evaluate the different motion conditions and methods for visual scene compensation. TACOM and RTI personnel drove the simulator over a mountain road database to evaluate its capabilities. The following are the observations gleaned from that study:

- Drivers perceived little difference between head tracking methods
- Roll, pitch, and vertical cueing were the best motion cues to present through the motion base
- Visual scene compensation requires more research
- The simulator visual update rates greater than 30 Hz to be effective
- Simulator sickness may be an issue and needs to be investigated further

Figure 1. 6 DOF mini-motion base.

1.2 Phase II Development

The Phase I proof of concept evaluation results were used to direct the Phase II research and development plan. Prior to running the Phase II experiments, numerous technical advances were applied to the motion base, control loading, and visuals subsystems to further enhance the simulation experience. The CAVE visual environment provided the capability to present active stereo or mono visual graphics depicting the off-road driving environment. The CAVE system was also modified to allow the use of a head mounted display (HMD) as another type of visual display to include in the comparison. Therefore, these three methods of graphics presentation would be analyzed for their potential use in the final system design.

General visual subsystem enhancements included an increase in display resolution from 1280 x 512 to 1280 x 1024 pixels per display wall or a calculated resolution of 6.17 arcmin/pixel in the vertical dimension. In addition, graphics rendering performance was enhanced to provide 48 Hz visual update in all visual modes.

A tracking device was also mounted to the motion base and its outputs were integrated with the visual system providing accurate, real time motion base orientation. This enhancement greatly increased the accuracy of motion base position compensation in visuals.

2.0 METHOD

In Phase II, two human factors research studies have been conducted on the steadily evolving CAVE-based driving simulator. For both experiments, a High Mobility

Multipurpose Wheeled Vehicle (HMMWV) model was generated and implemented in the simulator. In addition, a difficult off-road driving environment was generated that included challenging roadway grades, side slopes, and embedded obstacles such as exposed rocks and downed trees. Examples of the driving environments can be seen in figures 2 and 3.

The first experiment was designed to determine the optimal combination of visual system and motion cue algorithm types. The optimum configuration from the first experiment was then used as the test configuration for the CAVE simulator. The second experiment was designed to compare the driving performance of subjects in the CAVE simulator to another set of subjects performing the same driving tasks in TACOM's Ride Motion Simulator (RMS). In addition, two simulator sickness mitigation techniques were tested during the second study. These techniques included the presentation of an independent visual background (IVB) and the use of the ReliefBand active nausea mitigation device. The remainder of the paper will discuss the conduct and results of those studies.

2.1 Experiment #1

Twelve subjects recruited from TACOM personnel participated in the 3 day, repeated measures experiment. All subjects were between the ages of 18 and 25 and balanced equally by gender. All drivers had a valid Michigan driver's license and were not experienced HMMWV or simulator drivers.

The first experiment was designed to further evaluate the impact of varying the type of motion tuning and visuals presentation used for off-road driving. Based on the results of the Phase I proof of concept study, the motion base was configured to run in a 3 DOF mode using pitch, roll, and heave. Two 3 DOF motion models were developed. The first used a medium level of motion scaling (33%) and was called the "Mid" level motion. The other used a higher level of motion scaling (65%) and was called "Exp" for experimental. In addition to the 3 DOF motion algorithms, a no-motion condition called "None" was included to further validate Phase 1 findings that motion was beneficial to the simulation.

The first experiment also included an evaluation of visuals display presentation method on off-road driving performance. The visual conditions evaluated included CAVE active stereo, CAVE mono, and a head mounted display (HMD).

All combinations of visual display and motion type were tested and compared to one another. The result was a 3 (motion type) x 3 (visual display) full factorial, within subjects experimental design. With this design, each subject drove the simulator a total of nine times, once with each motion and visual display combination. The subjects participated for three days performing 3 drives each day. The visual system was the same for all drives on a given day and the motion condition varied between each drive. The order of presentation of conditions was randomized for each subject.

For each drive, the subject drove the simulated HMMWV vehicle over the same mountain driving course. Drivers were instructed to drive to the end of the course as quickly and safely as their comfort will allow without departing from the mountain road. They were to avoid and or traverse any hazards that present themselves on the roadway – rocks, ditches, logs, etc. as they completed the course.

In addition to the standard driving task of negotiating the off-road path to the finish, participants were asked to maintain a target speed and to position the vehicle in the center of a lane in four special zones. The four zones were defined by traffic pylons positioned on the off-road path as either straight or curved "lanes." All rocks and other obstacles were removed from the roadway in within the zones to provide a clear path for the drivers to follow. The straight sections consisted of 18 cones with nine per side positioned three meters apart laterally and five meters apart longitudinally down the road. The entire drive was designed to take about seven minutes to complete. An example of a curved zone may be seen in figure 3 below.

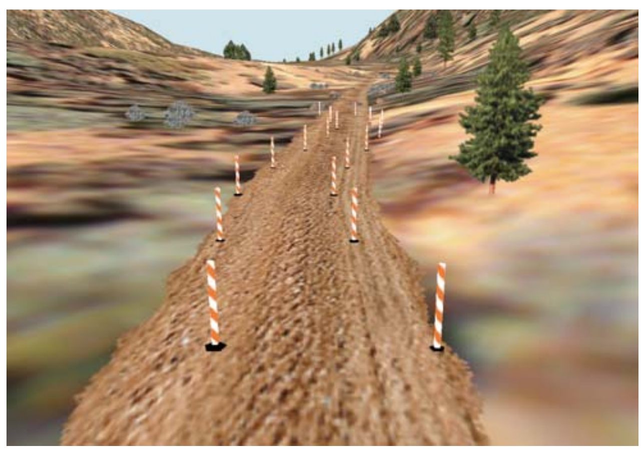

Figure 2. Example of curved cone segment.

Drivers were instructed to maintain a speed of 10 mph and to position the vehicle as close the center of the lane defined by these cones as possible. During the rest of the drive, the speed and vehicle positioning was at the driver's discretion.

The driving task performed inside the cone zones differs significantly from the normal off-road driving task. The roadway within the coned areas was free of rocks and other obstacles. A clear target path was presented to the

driver. In addition, there was a desired target velocity that the driver was attempting to maintain. Outside of the coned areas, the driver drove whatever path and velocity they were comfortable with. Based on these qualitative differences, we would expect driving behavior within the coned areas to be more similar to normal on-road driving.

At the very end of the drive, the subjects were asked to stop the vehicle with what they perceived to be the front bumper of the vehicle over a white stopping line that was embedded into the roadway. Their initial stopping point was recorded and a distance to stopping line measure was calculated for each drive.

Questionnaires were administered at various times during the study process. In general, there were five questionnaires used. The first was the Simulator Sickness Questionnaire (SSQ) as developed by Kennedy and his colleagues (Kennedy, Lane, Burbaum, and Lilienthal, 1993). The SSQ was administered at the beginning of the day to capture a baseline and once after each drive. The other 4 questionnaires focused on identifying the subjects' preferences and opinions regarding the visual display and motion conditions.

Performance measures were captured over the course of the entire drive and separately within each zone. Measures included mean velocity and steering rate, standard deviations of velocity, steering, brake, throttle, lateral acceleration, longitudinal acceleration, pitch, and roll, and number of rollovers, time to complete drive, and distance to a stopping line.

2.2 Experiment #2

Forty eight subjects recruited from TACOM personnel balanced equally by gender and divided into two age groups where the younger group included ages 18-24 and the older group included ages 45-65. All drivers had a valid Michigan driver's license and were not experienced HMMWV or simulator drivers.

The second human factors study included a comparison of driving performance between the CAVE-based driving simulator and TACOM's Ride Motion Simulator (RMS). The RMS is TACOM's 6 DOF, motion base simulator which is capable of high amplitude motion and 120 deg. forward FOV visuals-on-motion scene presentation. The CAVE was configured in the optimum design as identified in Experiment #1. In addition to the comparison between simulators, two simulator sickness mitigation techniques were also investigated. An independent visual background (IVB) was developed and applied to the CAVE portion of the study. The ReliefBand active motion sickness mitigation device was tested in the RMS portion of the study.

The experimental design for the second experiment was modified to include more subjects and fewer testing conditions. 24 of the subjects drove the CAVE simulator and 24 drove the RMS simulator for 2 successive drives of approximately 7-10 minutes each. Simulator type was a between subjects factor to eliminate the potential for skewed subjective opinion of the simulator caused by variance in magnitude of the facilities involved. Drive number was a within subjects factor where each subject drove the mountain road twice separated by a 15 minute break.

The 24 subjects that drove the CAVE simulator were presented with the IVB simulator sickness mitigation technique in either their first or second drive. All subjects in the RMS portion of the study wore the ReliefBand device and half of the 24 subjects activated it for both of their drives. The other half simply wore the device but did not turn it on. A representation of the IVB may be seen in the figure below.

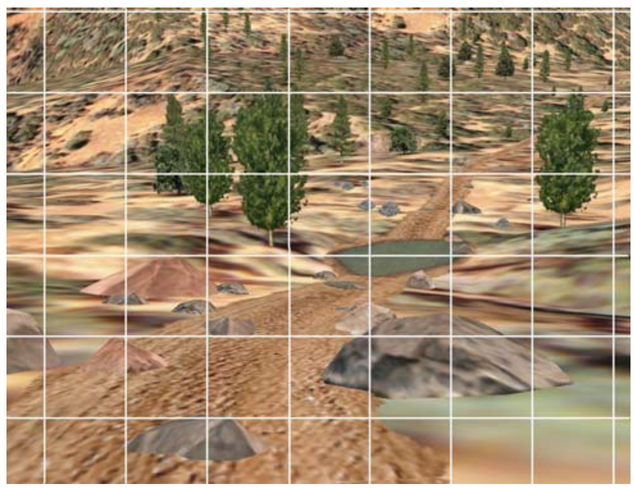

Figure 3. Out the window view with the IVB.

The driving task was the same as with the first experiment with the exception of the cone zones. An additional four zones were added to the scenario along with four additional stopping lines. These additional zones provided additional opportunities to measure and evaluate driving performance where path following and speed maintenance were more regimented than with the standard mountain road driving.

Each subject completed a Kennedy SSQ before they drove and after each successive drive. In addition, subjects also responded to a general questionnaire regarding simulator realism, a motion questionnaire regarding quality of motion, and a simulator sickness mitigation questionnaire where they provided opinions of how either the IVB or ReliefBand affected how they felt and drove.

2. RESULTS

There were a number of statistically significant results found for the measures analyzed in each experiment. A complete and thorough discussion of these results is beyond the scope of this paper and can be found in the final report for this SBIR project. The purpose of this paper is to present some of the highlights of the findings in both experiments.

3.1 Results for Experiment #1

The time to complete the drive indicates how long it took the driver to negotiate the entire off-road course from the time they started moving until they stopped at the end line. A significant main effect for motion condition was found. Drivers took significantly less time to complete the drive in the None motion condition than in the Exp or Mid motion conditions.

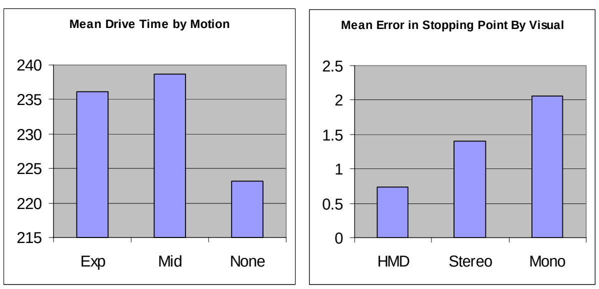

Figure 4. Mean time to complete drive by motion condition and mean error in stopping distance by visual condition.

The distance to stopping point is the resulting distance measurement between the front bumper of the virtual vehicle and the stopping line. A significant main effect of visual condition was found where the distance between the stopping point and the front bumper of the vehicle was shorter for the HMD than for the Mono condition. There were no statistically significant differences found between the Stereo condition and the other conditions.

Recall that subjects were asked to drive 10 mph and as close to the center of the cone lane as possible when in the zones. The next few results are from measures calculated from within the zones.

A two-way interaction between the motion and visual conditions was found significant. A simple effects analysis produced the following results. There were significant differences found between motion conditions when drivers were using the HMD where the Exp motion condition resulted in a greater offset than either the Mid and None motion conditions. There were also differences found between motion conditions for the Stereo visual condition where the Mid motion condition resulted in more offset than the Exp motion condition. There were no differences found between motion conditions with the Mono visual display.

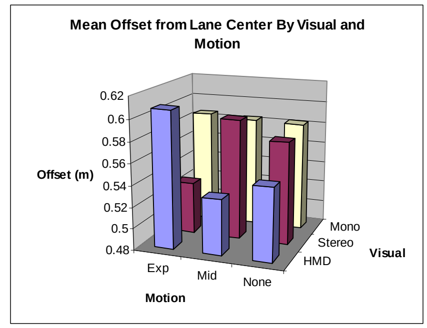

Figure 5. Mean offset from lance center by visual and motion condition.

A significant main effect of visual condition was found for mean velocity in zones. The post hoc analysis indicated that there was a significant difference between the HMD and Mono conditions. On average, drivers over estimated their speed by 5-8 miles per hour.

A significant interaction was found for standard deviation of steering wheel input by visual condition and zone curvature where no differences were found between visual conditions in the straight zones. However, in the curved zones, the HMD resulted in more steering input than the other visual conditions.

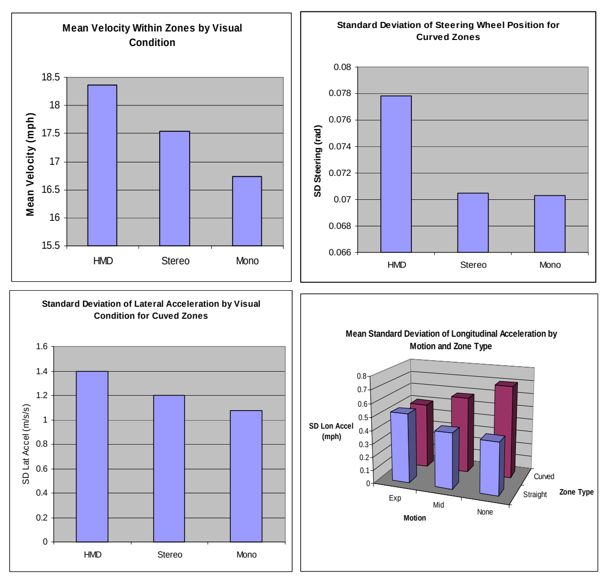

Figure 6. Mean velocity, standard deviation of steering wheel position, standard deviation of lateral acceleration by visual condition and standard deviation of longitudinal acceleration by motion condition and zone curvature.

The standard deviation of lateral acceleration corroborates other lateral performance measures and provides information about the magnitude of lateral correction the driver performed while driving through the zone. A significant visual condition by zone type interaction was found. A simple effects analysis of the curved data indicated a difference between visual conditions. The HMD resulted in more variance in lateral acceleration than the Stereo and Mono conditions and the Stereo resulted in more variance than the Mono condition.

Longitudinal acceleration variance gives us an indication of how smoothly the driver was able to control their vehicle while maintaining the target velocity. A significant motion by zone type interaction was discovered. For the straight zone data the Exp motion condition resulted in greater variance in longitudinal acceleration than the None motion condition. For the curved zone data, an opposite effect was found where the None motion condition resulted in more variance in longitudinal acceleration than the Exp motion condition.

3.2 Discussion of Results from Experiment #1

The HMD appears to have made some driving tasks more difficult than the Stereo or Mono displays. Drivers were found to drive with more accelerator input variability over the course of the entire drive when using the HMD. In addition, speed perception was poorer in the zone areas where subjects were instructed to maintain 10 mph. While subjects underestimated their velocity with all display types, error was greatest when using the HMD. Lateral maneuvering also seems to have been more challenging with the HMD. The HMD resulted in greater variance in steering wheel input as drivers negotiated the zones. In terms of maneuvering accuracy, it appears that with more motion cue inputs, drivers had more difficulty when using the HMD.

These results may be explained by several factors associated with the HMD device. The HMD provided a 40° horizontal FOV thus limiting instantaneous FOV while the Stereo and Mono conditions both provided 270° horizontal FOV. Reductions in FOV have been shown to affect speed perception where greater peripheral stimulus (wider FOV) resulted in increases in perception of self speed (Segawa, Ujike, and Saida, 2002). This implies that the sensitivity to perception of self speed may be reduced if restriction is placed on peripheral stimuli. Jamson (2001) did indeed find that widening the FOV on their conventional display driving simulator to 230° from 140° resulted in improved speed keeping and lane keeping performance. Therefore, it is quite likely that in this study, the reduced FOV displayed by the HMD resulted in less certainty about actual speed as compared to the Stereo and Mono conditions.

In general with respect to visual display conditions, several key differences were identified in the way drivers negotiated the zones. When using the HMD, drivers drove faster and had greater error with respect to the target speed. They also drove with greater variance in steering input, lateral acceleration, and heading. These results indicate that drivers were less aware of their speed and exerted more effort to control the lateral position of the vehicle.

It is not exactly clear why the Stereo condition did not result in more accurate speed perception as compared to the Mono condition. Previous studies in virtual reality research indicate the stereoscopic viewing and wider FOV increase vection or feelings of self motion. The Stereo condition (stereoscopic and wide FOV) should have resulted in greatest perception of speed causing drivers to drive slower (and more accurately) than with the Mono or HMD conditions. However, this was not the case.

One potential explanation for slower driving with the Mono condition is that drivers may have felt less comfortable picking out and maneuvering through the zone without the stereoscopic cues and consequently slowed the vehicle to help maintain accurate lateral position as they passed between the cones.

Different combinations of motion and visuals conditions also resulted in differences in the driver's ability to precisely maneuver the vehicle. We would expect drivers to have less success with precision maneuvers with the HMD due to the lack of peripheral visual stimulation and the interference it has been show to cause in lane tracking (Jamson, 2001; Kappe, van Erp, and Korteling, 1999; DeVries and Padmos, 1997) and understanding subtle self-rotation (Schulte-Pelkum, Riecke, and Von der Heyde, 2003). Drivers tended to drive faster and maneuver more aggressively when using the HMD within cone zones in this study. This is evidenced by increases in standard deviations of steering input, heading error, and lateral acceleration as compared to the other visual conditions, particularly in the curved zones.

There appears to be a difference in how motion condition affects driving performance based on the maneuvering requirements of the environment and in the straight zones where the maneuvering requirement was minimal. Drivers drove with less velocity variance but more accelerator pedal position variance. If we look at the measures that resulted in significant visual condition effects for driving performance within the zones, we find that they are primarily related to the lateral positioning and maneuvering of the vehicle. In contrast, it appears that the significant motion condition effects are more related to longitudinal control of the vehicle.

3.3 Results for Experiment #2

A number of interesting results were found significant in experiment two. To keep this paper at a reasonable scope, only a few of the highlights will be presented.

A significant simulator by curvature interaction was found for the distance from the center of the cone lane. The simple effects analysis indicates that in the straight zones, the offset was less in the RMS as compared to the CAVE.

The standard deviation of steering input provides information about how much effort the driver expended to steer the vehicle to the center of the path defined by the cones. More steering variance indicates greater effort by the driver. A significant simulator by curvature interaction was identified. An exploration of the simple effects indicates that there was a significant simulator main effect where for each level of curvature, the RMS drivers exhibited less steering variability than the CAVE drivers.

A significant simulator by curvature interaction was also found for mean speed. An analysis of the simple effects indicates that in the straight zones, the RMS resulted in faster driving than the CAVE. Recall that the target velocity for the zones was 10 mph. The mean velocity for all drives by simulator was 23.1 mph for the RMS and 21.6 mph for the CAVE. So all drivers were underestimating their speed during this study.

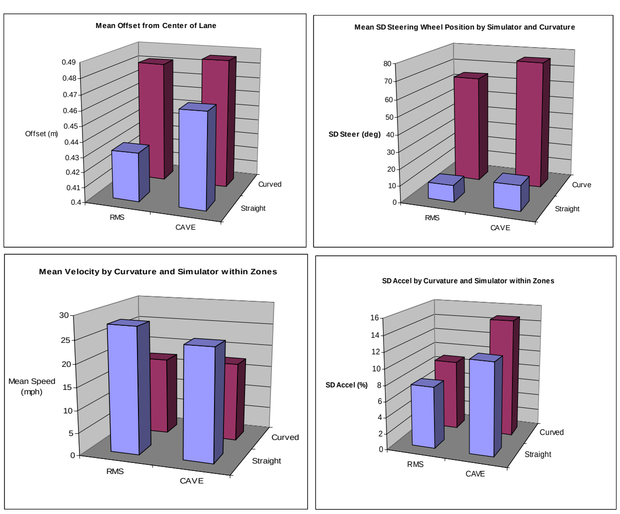

Figure 7. Mean offset from lane center, mean standard deviation of steering wheel position, mean velocity and standard deviation of accelerator pedal by simulator and curvature.

Accelerator pedal position variance gives us an indication of how actively the driver was working the throttle to maintain their target velocity. A simple effects analysis of simulator by curvature reveals a similar effect where in the curved zones, CAVE simulator drivers had more throttle input variability than RMS drivers. There were no differences in throttle usage between simulators in the straight zones.

The Kennedy SSQ was administered to all subjects after each of their test drives. Recall that the drivers on the RMS wore the ReliefBand nausea mitigation device, half had the device turned on and half had it turned off. The results were analyzed to determine if the system had any effect. A significant mitigation by trial interaction was found for the DISO subscale. A simple effects analysis dividing the data by trial number shows that there were no differences between using the ReliefBand and not using the ReliefBand in the first drive. However, in the second drive, the mean DISO score was higher with subjects that were not using the ReliefBand as opposed to those that were.

The mitigation by drive number interaction for the OCUL score was also close to significance. Normally we would not report on any marginally significant scores but since this study is exploratory in nature, we feel it is valuable to describe any trends in the data that might provide useful insight for anyone wishing to continue the evaluation of the ReliefBand for reducing simulator sickness. A power analysis of the data for the OCUL scores indicates that with just 2 more subjects, the interaction effect would have been found significant. The same trend is seen with the OCUL subscale score where the ReliefBand resulted in lower reports of simulator sickness scores after the second drive.

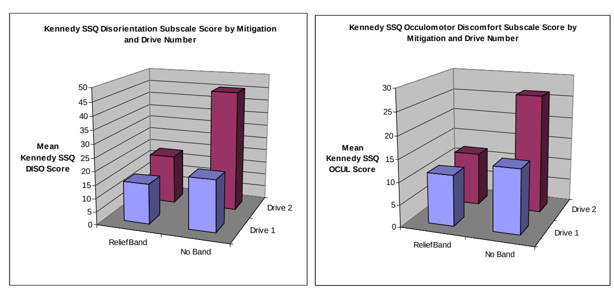

Figure 8. Mean Kennedy SSQ disorientation and coulometer discomfort subscale scores with and without the ReliefBand.

3.4 Discussion of Results from Experiment #2

A number of measures in the second study indicate that drivers in the CAVE required more manual effort to control the vehicle while driving through the zones. This is particularly true in the curved zones where the demands of the maneuvering task were greatest. The types of motion cues presented by the simulators provided a possible explanation for this phenomenon. The RMS

provides large amplitude 6 DOF motion cues. The CAVE was configured to provide 3 DOF motion cues of roll, pitch and heave. Therefore, the RMS provided immediate lateral and longitudinal acceleration information which should have helped drivers have a better feel for the results of control inputs. In the CAVE without these cues, drivers were required to evaluate resulting accelerations based only on visual feedback and what they could discern from pitch and roll cues from the motion base. This represents less than perfect or timely information for the CAVE drivers. Therefore, it appears that the immediate lateral acceleration cues provided by the RMS did help drivers maneuver through the cone obstacles with less steering effort while maintaining the same level of accuracy as with the CAVE simulator.

Driver's control of velocity as they drove through the cone zones also appears to have been affected by the type of simulator driven. The significant simulator by curvature interaction for accelerator pedal input variance also shows that drivers exhibited more variance in the CAVE than on the RMS on the curved zones where the attention demands of maneuvering were there highest. As a whole it would appear that drivers were able to drive the RMS simulator through the zones with less maneuvering effort than the CAVE while maintaining a similar level of accuracy.

The results show that for the DISO subscale score (and marginally the OCUL subscale score), the ReliefBand appears to have resulted in no increase in simulator sickness scores with increased exposure. This same trend appears in the other subscale and total severity scores but was not found statistically significant. This is an interesting finding in that it appears that with increased exposure, the ReliefBand may provide some amount of reduction in simulator sickness symptoms. In fact, the scores for the significant DISO interaction show that with the ReliefBand, the scores between the first and second drives showed virtually no increase at all. The scores without the ReliefBand show a definite upward trend with increased exposure.

4. CONCLUSIONS

A summary of all results for the first experiment is as follows:

- There were very few differences in performance between the Stereo and Mono visual conditions
- The HMD resulted in poorer speed perception and velocity was more difficult to maintain
- The HMD resulted in more lateral control effort to maneuver through the cones
- The HMD resulted in better accuracy stopping at a stopping line
- Drivers did not express a clear preference for any of the visual conditions
- The drives with motion cueing resulted in more realistic speed selection and maneuvering response than the non-motion drives
- There were very few performance differences in results found between the high and medium motion tuning parameter sets
- Drivers preferred the high and medium motion conditions to no motion but did not distinguish between them

A summary of conclusions for the second experiment include the following:

- In general, driving performance between the CAVE and RMS were fairly similar.
- There were differences in performance between the RMS and CAVE relating to speed keeping performance.
- Driving performance appears to have been more consistent between the first and second drives on the RMS as compared to the CAVE.
- Drivers exhibited more control input in the CAVE when driving through the curved zones.
- Drivers underestimated their speed in the zones in both simulators.
- In general, simulator sickness measures were the same between the RMS and CAVE simulators.
- The ReliefBand appears to have limited the increase in simulator sickness symptoms between the first and second drives.

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